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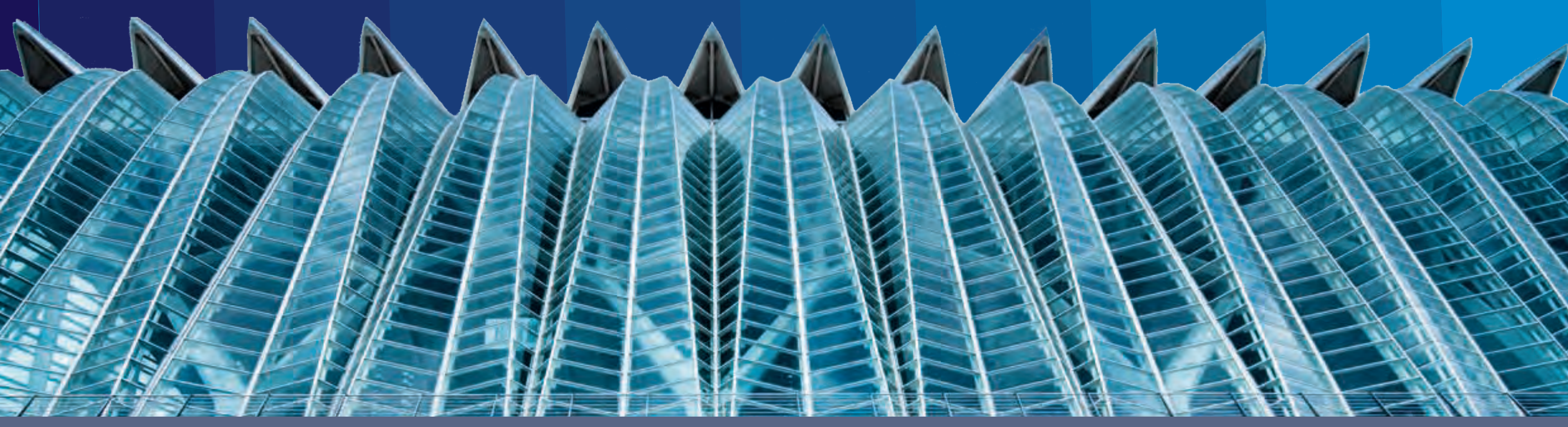

Rethinking Learning in a Connected Age

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AN INNOVATIVE PRACTICE IN THE PHYSICS LABORATORY: RADIOFREQUENCY ELECTROMAGNETIC FIELDS PERSONAL EXPOSURE

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Abstract

During last decades, personal exposure to Radiofrequency Electromagnetic Fields (RF-EMF) has experimented an important increase due to the development of the information society, and at some point, we have wondered whether these have any negative effects on health, some out of concern and some out of curiosity. At the same time, concerns regarding potential health effects have also increased.

In this context, development of portable devices allowed to study personal exposure to RF-EMF in detail (spatial, temporary, number of bands, accuracy, etc.).

It has been shown that this knowledge helps the general public to reduce their concerns and fears about improbably health effects of RF-EMF. During university training, involving students in the design and development of the determination of personal exposure to RF-EMF through a laboratory practice, could provide a better approach and understanding of the problem.

In this work, we explore the design and development a practice in the Physics laboratory for Computer Science Engineering students where the main objective was to measure the personal exposure to RF-EMF from 14 different frequency bands using a personal exposimeter.

The practice was developed at the Faculty of Computer Science Engineering at the University of Castilla-La Mancha (Albacete, Spain). Students used a Satimo EME Spy 140 personal exposimeter, and data analysis was performed using EME Spy Analysis Software v3.20 and MS Excel. Students checked that measures were well below healthy limits established by the International Commission on Non-Ionizing Radiation Protection (ICNIRP) and reference levels allowed by the European, Spanish and Castilla-La Mancha legislation.

This practice showed that involvement of students in the development of this type of measures, not only allows a better understanding of propagation and measurement of the RF-EMF but also allows to reduce possible concerns regarding potential effects on Health. This laboratory practice can be easily replicated in other universities.

Keywords: Wave Intensity, Radiofrequency Electromagnetic Fields, Personal Exposure.

1. INTRODUCTION

This work deals with measures of personal exposure to Radiofrequency Electromagnetic Fields (RF-EMF) in a Spanish university (UCLM, Albacete campus); obtained in the 14 frequency bands, comparing the measurements obtained from the total of all the bands and those obtained from the Wifi antennas; since in previous measurements in this city, it was identified that the highest levels recorded in the university area are those coming from this type of antennas [1], [2].

Therefore, the decision is made to prepare a protocol to measure at the University, making the measures in this first stage in the Faculty of Computer Science Engineering at the University of Castilla-La Mancha (Albacete, Spain). The measurement protocol was designed as a possible practice of the Physics

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Laboratory of the subject Physics for Computer Science Engineering for students to participate in this type of studies, and apply the knowledge acquired in the classroom.

1.1. Electromagnetism

In 1864, Maxwell demonstrated that both electricity and magnetism were expressions of the same physical concept: electromagnetism. He related electricity to magnetism through his famous equations, which allowed the first partial unification of the four physical forces (gravitational, electromagnetic, weak and strong). It also demonstrated the existence of electromagnetic waves and although at first, they were identified with visible light, today we know that there are a large number of types of electromagnetic waves.

If there are accelerating charges, both the electric and magnetic fields vary in time, producing the propagation of their properties through space, forming a single electromagnetic wave. These fields, electric and magnetic, are perpendicular to each other and, at the same time, perpendicular to the propagation direction of the wave.

An electromagnetic wave is characterized by its speed, wavelength, frequency and phase of the electric and magnetic fields that compose it, as well as its amplitudes. The wavelength (λ) and the frequency (ν) are related to the propagation speed (c) in the following way: $c = \lambda \cdot \nu$

1.2. The electromagnetic spectrum

The different types of radiation differ from each other in their frequency and wavelength. The electromagnetic spectrum encompasses the entire electromagnetic radiation and classifies it according to their energy, and hence with its frequency, from the radiation of minor wavelength (higher frequency), as the gamma rays and X-rays, passing by the ultraviolet light, the visible light and the infrared rays, until the electromagnetic waves of greater wavelength (less frequently), like the radio waves. This is visualized in the so-called Electromagnetic Spectrum (Figure 1).

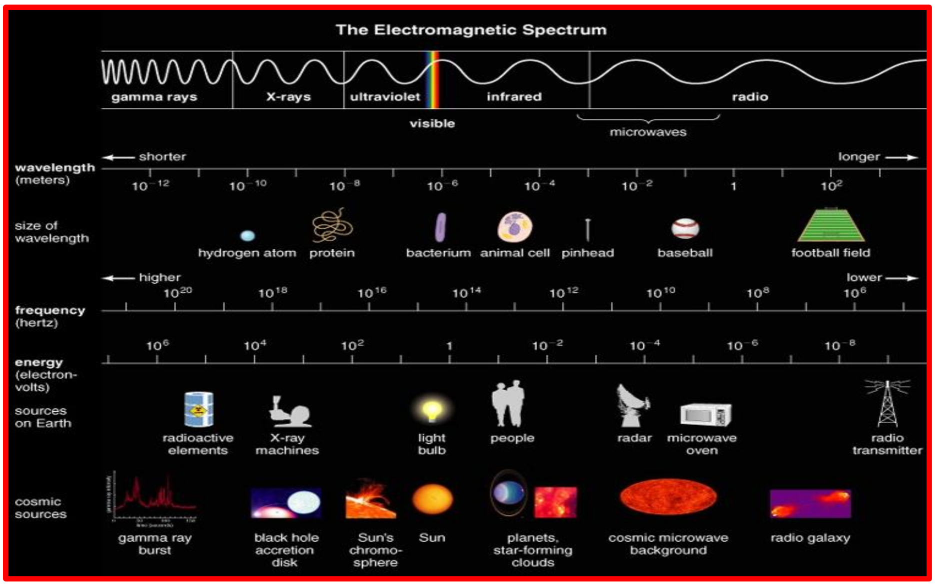

Figure 1. The Electromagnetic Spectrum (taken from https://www.are.na/block/1013351)

The electromagnetic spectrum usually ranges from frequencies of 10^3 *Hz* to frequencies up to 10^{23} *Hz*, so it is represented on a logarithmic scale. In addition to the division into the main bands, according to the ability to interact with matter, electromagnetic radiation can be divided into ionizing and non-ionizing radiation. This study considers non-ionizing radiation.

1.3. Basic regulations and legal reference levels

The International Commission on Non-Ionizing Radiation Protection (ICNIRP) together with the World Health Organization (WHO) have developed a few guidelines on exposure [3], [4], which lay down the limits to the different types of non-ionizing radiation and that are used to develop legislation in this regard. The *SAR* is defined as the power absorbed per unit of the body tissue mass and its average is calculated in the whole body or parts of it. It is expressed in watts per kilogram (*W/kg*). In 1998 the ICNIRP published the guidelines that limit the exposure to the public in general, based on the fact that the

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radiation absorbed should not increase the temperature of the human body by more than 1°C, because this could alter some of its functions. It is estimated that for it to produce adverse effects there should be a lack of *SAR* greater than 4 *W/kg* [5]. On the other hand, the reference levels for the power density of frequencies of 2 to 300 *GHz*, for occupational exposure is 50 W/m^2 and for exposure of the general public 10 W/m^2 [4], [6].

The maximum level of exposure allowed to the RF-EMF, on the urban soil of Castilla - La Mancha (our region), is **0.1 W/m^2**, regardless of the frequency. This value is the tenth part of the value that marks the Spanish legislation. For the sensitive centers inside (schools and hospitals) the maximum level of electromagnetic wave intensity for frequencies of mobile telephony (GSM, DCS and UMTS) is **0.001 W/m^2** [7].

1.4. Exposimeters

The World Health Organization indicates the need to improve the assessment of exposure to RF-EMF for conducting epidemiological studies. It is necessary to know in detail the exposure of the population to these emissions, in order to be able to compare them with the standard insurance collected in the legislation in force [8]. People move through space along their everyday life and the radio frequency (RF) emissions may also vary within time and space. Therefore, in many situations, it is appropriate to have an instrument that can be worn or carried on the body and that measure the RF-EMF of an exposed person, when working or when they are performing another type of activities, that was how I was developed the first exposimeters [9], [10].

The narrowband exposimeters discriminate by frequency band, providing a more detailed description of the exposition [10]. The exposimeter Satimo EME Spy is capable of measuring up to 20 frequency bands (Model 200), 88 *MHz* to 5850 *MHz*, identifying the contribution of each issuer to total field. It is also capable of recording measures in periods of time between 2 and 255 seconds. The exposimeters Spy of the last generation allow us to observe the measurements in real time through an application of Android for the mobile phone [11]. The sensitivity of the exposimeter varies, for model Spy 200, between 0.3 $\mu W/m^2$ and 0.06 $\mu W/m^2$, depending on the frequency band.

1.5. Studies with personal exposimeters

Some of the studies performed using personal exposimeters, which have characterized the personal exposure to RF-EMF and/or analyzed the exposure in different microenvironments, are briefly described below. **Netherlands:** Bolte et al. [12]. **Greece:** Manassas et al. [13]. **Switzerland:** Röösli et al., [14] and Frei et al. [15] they describe exposure levels and the contribution of different sources of RF-EMF in Basel (Switzerland) using EME Spy 120 exposimeters. Sagar et al. [16], use portable exposimeter to monitor personal exposure to EMF-RF. **Germany:** Thomas et al. [17]. The general exposure to EMF-RF was well below the reference level ICNIRP. **Hungary:** Thuroczy et al. [18]. **France:** Viel et al. [19] **Belgium:** Joseph et al. [20], were focused on different microenvironments. Verloock et al. [21], characterize the exposure in areas where the presence of children is important. Aminzadeh et al. [22] used personal exposimeters under diffuse indoor exposure. **Australia and Belgium:** Bhatt et al.[23], evaluated the personal exposure of various EMF-RF sources in 38 microenvironments (19 in each country) using two exposimeter systems. The exposure levels obtained were well below the general public reference levels recommended in the ICNIRP guidelines [4] and the Australian Radiation Protection and Nuclear Safety Agency (ARPANSA) [24]. **Spain:** Gonzalez-Rubio et al. [1], [2], [25], Mortazavi et al. [26], Arribas et al. [27], Najera et al. [28], Sanchez-Montero et al. [29], Fernandez-Garcia and Gil [30], they evaluated the personal exposure to RF-EMF and the results of the measurements show that the electromagnetic fields are much lower than the safety levels according to ICNIRP.

Simultaneously with the increased exposure to RF-EMF produced in the last decades, the population's concern about the possible effects on health has increased [10], making multiple epidemiological and experimental studies in this regard.

1.6. Spatial Data Analysis

Spatial data represents information about the physical location and shape of geometric objects [31]. Analysis of spatial data or analysis of geographic information involves at least four large areas identifiable in the bibliography, each using the term differently [32]: Spatial data manipulation; Analysis of spatial data descriptive and exploratory; Spatial statistical analysis; and Spatial modelling. First, the data is collected, visualized, and described [33], [34]. Subsequently, through different exploratory techniques, theories about the phenomena of interest are presented. These theories are then tested using spatial statistical techniques [35]–[37]. Theories could then be the basis of computer models of

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phenomena [38]–[40], and their results may, in turn, be the subject of new research and analysis [39], [41], [42].

The spatial statistics classify into three broad areas [39]: Spatial patterns of points, Area or aggregate data, and Geostatistics. These tools are used in this study to develop intensity maps and will serve as the basis for future epidemiological studies [43].

1.7. ArcGIS Software

The Geospatial Information System (GIS) superimpose data on geographic maps to provide visual representations of data by region [44]. ArcGIS, is an information system provided by ESRI (Environmental Systems Research Institute) that connects maps, applications, data and people so that decisions can be made; providing the ability to create, analyze, store and share maps.

1.8. Kriging method

The Kriging method performs the interpolation on a set of scattered data. It was originally developed in geostatistics (also known as spatial statistics) for South African mining [43]. It is a non-skewed linear interpolation method that predicts the value of a function in a zone using a weighted linear combination of all measured values [45]. The Kriging method is able to generate the model for the irregularly spaced points of a sample and for cases where the sampling points suggest that the observed trend has peaks and valleys [46].

2. METHODOLOGY

2.1. Exposimeter EME Spy 140

The personal exposimeter selected to carry out the experimental work is the Satimo EME Spy 140 model (Figure 2), which has dimensions of 168.5 *mm* (height) x 79 *mm* (length) x 49.7 *mm* (width) and a mass of 0.410 *kg*. The main characteristics of the exposimeter are the capability to measure up to 14 frequency bands (from 88 *MHz* to 5 *GHz*) with a maximum sensitivity of 0.005 *V/m* (Table 1) and identifying the contribution of each emitter to the total field. It can register 12540 measurements in time periods ranging from 4 to 255 s. The minimum value that the exposimeter detects for each band is as follows: FM: 0.0007 $\mu W/cm^2$, TETRA, TV4 & 5: 0.00003 $\mu W/cm^2$, GSM, DCS, DECT, UMTS, Wifi 2G: 0.000006 $\mu W/cm^2$ y TV3, Wimax, Wifi 5G: 0.0001 $\mu W/cm^2$.

Figure 2. Personal exposimeter, Satimo EME Spy 140 model.

Table 1. The 14 RF-EMF Bands in which the EME Spy 140 measures.

Band	Description	Frequency (*MHz*)
FM	FM radio signal.	88 – 108
TV3	Television signal.	174 – 223

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TETRA	Mobile communication for closed groups.	380 - 390
TV4&5	Television signal.	470 – 830
GSMxUL	Transmission from a mobile phone to a base station.	880 – 915
GSMxDL	Transmission from the base station to a mobile phone.	925 – 960
DCSxUL	Transmission from a mobile phone to a base station.	1710 – 1785
DCSxDL	Transmission from the base station to a mobile phone.	1805 – 1880
DECT	Digitally enhanced wireless telecommunications.	1880 – 1900
UMTSxUL	Transmission from a mobile phone to a base station.	1920 – 1980
UMTSx(DL)	Transmission from the base station to a mobile phone.	2110 – 2170
Wifi 2G	Wireless local area network.	2400 – 2500
Wimax	Worldwide interoperability for microwave access.	3400 – 3800
Wifi 5G	Wireless local area network.	5150-5850

2.2. Study area

The study area selected for the development of the laboratory practice was the building “Infante Don Juan Manuel” in the University of Castilla la Mancha campus of Albacete (Figure 3). From this area, twelve key points were selected abroad, identified from point A to point L. The measurements were made in the morning.

Figure 3. Building “Infante Don Juan Manuel”, Albacete (Spain) and the points marked to measure.

2.3. Objective

Measure the intensity of the radiofrequency waves emitted by the electromagnetic fields (RF-EMF), in 14 different frequency bands, comparing the measurements obtained from the total of the bands and those obtained from the Wifi antennas, in the building “Infante Don Juan Manuel”, shared by the Faculty of Computer Science Engineering and the College of Industrial Engineering.

2.4. Development

For the development of the practice you need the collaboration and support of the teacher, to know the basic operation of the Personal Exposimeter Satimo EME Spy 140; for example, the configuration of the equipment, download and save data of the measurements made in the format of the software

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implemented by the exposimeter EME Spy 140 (EME Spy Analysis v3.20) and in Excel format (.xls); and the generation of graphs that show the intensity of the radiofrequency waves emitted by the electromagnetic fields (RF-EMF), besides analyzing and interpreting them to obtain conclusions.

Considering the above, and achieve the correct development of the practice by the student, the teacher delivers the exposimeter EME Spy 140 configured and ready to make the measurements; explains the measurement protocol in which the chosen points are indicated, and measurements are taken.

The measurement protocol has been designed so that it can be adapted and applied in different colleges, even to be applied in other cities and countries, since in our research team there are teachers from Mexico, Colombia and Brazil. The stages that must be considered are the following:

1. Measurement area: identify the college where the measurements will be made and with the support of a Google Earth map or Google Maps select the area that wants to be measured. In this case, the aforementioned building was chosen (Figure 3).
2. Determine and trace the key points to measure, in our case, the 12 points shown in Figure 3 (A-L points).
3. According to the plotted points, the dwell time to measure at each point is calculated. It is determined to measure for 2 minutes, setting the exposimeter to measure every 5 *s*, obtaining a total of 24 measurements per point; adding 288 measurements for 1440 *s* equivalent to 24 minutes, without considering neither the time elapsed to move from one point to another nor the measures taken during that time.
4. To avoid shielding the body during the measurement process [47], a cardboard tube of 1.5 m is prepared in which the Satimo EME Spy 140 Exposimeter is clamped (Figure 4).
5. Once the configuration and operation of the exposimeter have been checked, we take measurements, considering that, when starting and concluding the two minutes of time established to measure at each point, a mark is made by pressing the power button on the computer. In this practice, the measurements were made in the morning.
6. After completing the measurement process, the measurements obtained are downloaded through the EME Spy Analysisv3.20 software and saved in Excel (.xls) to proceed with the analysis of the data.

Figure 4. Realization of the measurements and cardboard tube in which the meter was placed to avoid, as far as possible, the effect of the body.

3. RESULTS

The analysis of the intensity of the waves emitted by the RF-EMF is made with the total measurements of the 14 bands, and also with the measurements obtained only from the Wifi band (Table 2); for this, the marks made by each point are identified and only those measurements that are in the range of 2 minutes established (every 5 s) are chosen, that is, the 24 measurements taken in the morning at each point.

The mean values of each measured point are calculated (*nW/cm²*), afterwards, the maps are elaborated using the Kriging method. For this, the geographical location of the measured points is identified through Google Earth and the coordinates are obtained as shown in Table 2.

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Table 2. Intensity of the electromagnetic wave (nW/cm²).

Points	Intensity of the electromagnetic wave (*nW/cm²*)		Coordinates	
	14 bands	Wifi	E	N
A	8.12	3.05	598930,50	4315031,92
B	3.45	1.58	598959,78	4314993,87
C	1.35	1.24	598989,10	4315002,38
D	1.92	1.75	599017,41	4315007,95
E	0.68	0.57	599045,95	4315010,66
F	0.99	0.68	599073,74	4315015,04
G	14.20	6.18	599100,30	4315061,36
H	16.04	1.77	599061,66	4315077,86
I	9.76	1.30	599034,67	4315074,10
J	4.13	0.24	599007,39	4315070,24
K	9.26	4.76	598980,31	4315066,18
L	25.13	21.18	598948,35	4315072,85

The mean values and coordinates obtained are exported to the ArcGIS software, and through the Kriging method, the students must prepare the maps that show the intensity of the waves of the RF-EMF received in the morning, of the 14 bands and of the Wifi band (Figure 5), on a normal class day.

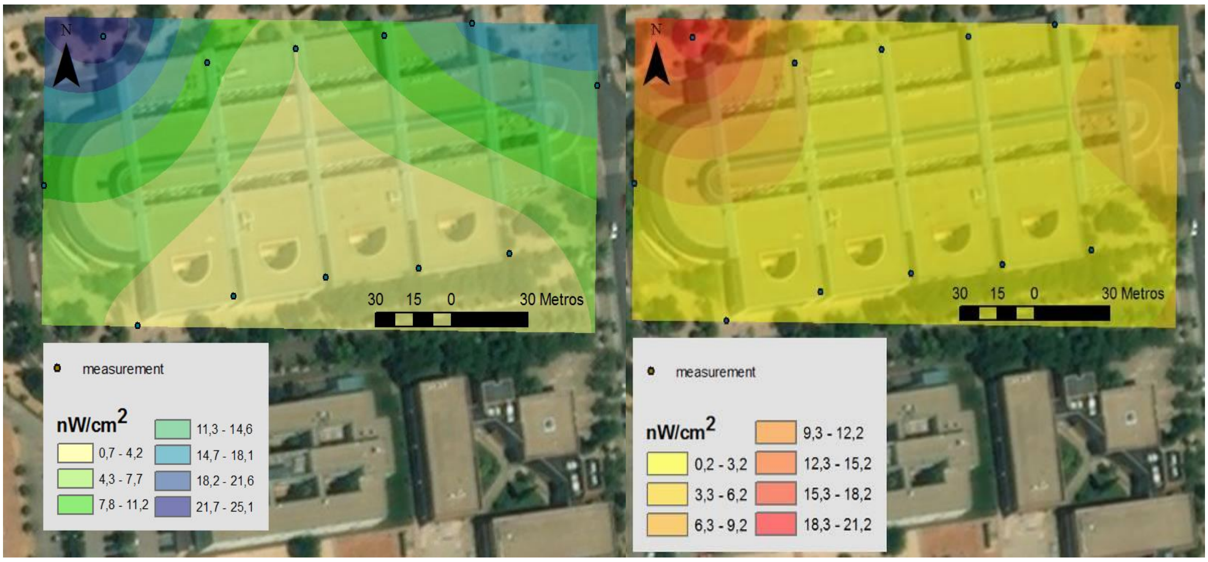

Figure 5. Intensity of the electromagnetic waves of the RF-EMF in nW/cm². On the left, we have the total intensity of the 14 bands and on the right only the Wifi band.

4. CONCLUSIONS

With the development of this practice for the first-year students, the levels of intensity of RF-EMF received in the morning on a normal class day have been identified in the building “Infante Don Juan Manuel”, shared by the Faculty of Computer Science Engineering and the College of Industrial Engineering, located in the University of Castilla-La Mancha, campus of Albacete, Spain.

When reviewing and analyzing the maps (Figure 5) and comparing the results with the maximum permitted level of exposure to non-ionizing electromagnetic fields established in Law 8/2001, for the Regulation of Radiocommunication Installations in Castilla-La Mancha; we realize that they are well below the limit allowed in urban land in Castilla-La Mancha is 10^4 *nW/cm*^{2}, regardless of the frequency of radiation.

If we take into account the national regulation RD 1066/2001, instead of the autonomic one that is quite more restrictive, the maximum value is 10^5 *nW/cm*^{2} and the measurements obtained are also very far from this value.

In the intensity maps of Figure 4, we can see that the highest levels are at point L, and at this point, it is where most of the students concentrate to connect to internet to send messages through Messenger, Whatsapp, check emails, or even watch videos.

Our intention, in the near future, is to repeat the measures again, in another day of normal class in the morning and, if possible, in the afternoon. We also want to do them on a Saturday, the day there are no classes at the university, inside and outside the University.

The measurement protocol designed allows this work to be reproduced in other faculties of the own University of Castilla-La Mancha or even, it can be adapted and applied in other universities in order to make comparisons of the different levels of intensity of RF-EMF received. Our research team has professors from several countries: Mexico, Colombia, Brazil, and we would like to replicate this practice in those other countries to be able to buy the results obtained.

This methodology can also be adapted and applied in other microenvironments, for example, a room, a shopping center, a soccer field, a hospital, etc. The possibilities that are presented to us are varied.

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